DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
WASHINGTON

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METHODS AND APPARATUS FOR MEASUREMENT OF THE FREQUENCIES OF DISTANT RADIO TRANSMITTING STATIONS.

Contents

I. General

Measurements of station frequency are necessary in order to utilize the standard frequency signals transmitted by the Bureau of Standards or the "standard frequency" and "constant frequency" stations listed in the Radio Service Bulletin each month. (The Radio Service Bulletin is a monthly publication of the Department of Commerce and is obtainable from the Superintendent of Documents, Government Printing Office, Washington, D.C., at 25 cents per year). Detailed descriptions of methods, and of an assemblage of apparatus and its use, are given herein.

A. Radio Signals of Standard Frequency.- The Bureau of Standards transmits radio signals of definitely announced frequencies, once a month, for adjusting and calibrating frequency meters (wavemeters) and other apparatus.

The signals are transmitted from the Bureau's station, WWV, at Washington, D.C. The frequencies included are from 125 to 6000 kilocycles. Announcements of the dates and other details of the schedules of transmission are given in the newspapers and radio magazines and in the Radio Service Bulletin.

Standard frequency signals are also transmitted by station IXM, Massachusetts Institute of Technology, with the cooperation of the American Radio Relay League and the approval of this Bureau. They are in the frequency range 3500 to 30 000 kilocycles, and are of special interest to radio amateurs. They are transmitted about twice a month, the schedule being published in the amateur radio periodical called QST.

The "standard frequency" and "constant frequency" stations listed in the Radio Service Bulletin serve the same general purpose as the Bureau's standard frequency transmissions. Frequencies from those stations have the advantage of being available every day. On the other hand, they are not certain to have as great accuracy as the Bureau's standard frequency signals.

The Bureau's monthly transmissions of standard frequency signals from station WWV are by continuous-wave radio telegraphy. The schedule begins at 10:00 P.M., Eastern Standard time. The complete schedule consists of eight frequencies approximately equally divided over the frequency range to be covered.

A single frequency transmission lasts 8 minutes. There is then a 4-minute interval during which the transmitting set is adjusted for the next frequency. The wording used in the four parts of a single frequency transmission is as follows:

General Call	"QST QST QST DE WWV WWV WWV -...- STANDARD FREQUENCY SIGNALS -...- FREQUENCY (statement of frequency) kc" (Repeated for 2 minutes).
Standard Frequency Signal	"WWV (long dashes) WWV (long dashes)" (Repeated for 4 minutes).
Announcement of this Frequency	"QST QST QST DE WWV WWV WWV FREQUENCY (statement of frequency) kc" (repeated for 1 minute).
Announcement of next Frequency	"QSY TO (statement of next frequency) kc QSY TO (statement of next frequency) kc .-.-." (Repeated for 1 minute).

At the end of the evening's transmissions, an announcement is given of the date and frequency range of the next scheduled transmissions.

The following is a sample schedule, the dates being correct for 1927.

Schedule of Frequencies in Kilocycles

(Approximate wave lengths in meters in parentheses).

Eastern Standard Time	Jan.20	Feb.21	Mar.21	Apr.20
10:00 to 10:08 P.M.	125 (2400)	300 (1000)	3000 (100)	550 (545)
10:12 to 10:20 P.M.	133 (2254)	315 (952)	3300 (91)	630 (476)
10:24 to 10:32 P.M.	143 (2079)	345 (869)	3600 (83)	730 (411)
10:36 to 10:44 P.M.	155 (1934)	375 (800)	4000 (75)	850 (353)
10:48 to 10:56 P.M.	166.5 (1800)	425 (705)	4400 (68)	980 (306)
11:00 to 11:08 P.M.	205 (1463)	500 (600)	4900 (61)	1130 (265)
11:12 to 11:20 P.M.	260 (1153)	600 (500)	5400 (56)	1300 (231)
11:24 to 11:32 P.M.	315 (952)	666 (450)	6000 (50)	1500 (200)

Note: For future current schedule of transmissions, address request to Bureau of Standards.

B. Outline of Methods.- The measurement of a station frequency may be for either of two purposes, (a) to standardize a frequency meter or other apparatus in terms of the station's frequency, or (b) to determine the station's frequency in terms of standard apparatus. The methods and instruments used are the same for either purpose. Accurate measurements are made by the "zero beat method" (described in detail in Part IV below) which requires the use of a receiving set, a frequency meter (wavemeter), and a radio-frequency generator. A simpler method, reliable to an accuracy of about 1%, is the "resonance click method," which requires the use only of a receiving set and a frequency meter. The simplest measurement of all is the approximate calibration of a receiving set in terms of known station frequencies, which requires only the receiving set.

For the purpose of this simplest type of measurement, it is only necessary to plot a curve showing the relation between tuner setting and frequency, or to mark the frequency corresponding to

different settings directly on the tuner dials. In a two-circuit
set, only the secondary circuit need be calibrated. Care should
be taken to note the settings of the dials of the coupling control
and the regeneration control when the calibration is made, and
these same settings should be used when any reference is made to
this calibration because a change in either coupling or regenera-
tion may cause a change in frequency. Changing the detector tube
will also affect the frequency calibration. In calibrating a
single-circuit receiving set it must be remembered that a change
of antennas or any change in the antenna constants after the set
has been calibrated will destroy the accuracy of the calibration.
A two-circuit tuner may be used on different antennas with little
change in accuracy since the secondary circuit calibration will
remain practically constant with changes in antenna constants pro-
vided loose coupling is used between the primary and secondary
circuits. The calibration of most receiving sets should be con-
sidered as only approximate since the calibration is changed by
various adjustments and other factors in the use of the set.

     The "resonance click method" is intermediate in accuracy and
complexity between the simple receiving set calibration just des-
cribed and the zero beat method. In measuring a distant station
frequency by the resonance click method the frequency meter is
coupled to a regenerative receiving set in a generating ("oscil-
lating") condition and which is then tuned to produce zero beat
with the incoming signal. The setting of the frequency meter is
varied until a click is heard in the telephone receivers of the
receiving set. This click is caused by the sudden absorption of
power from the receiving set circuit by the frequency meter. If
the coupling of the frequency meter to the receiving set is too
close, the click will probably be heard with different settings
of the frequency meter, depending upon whether the capacity of
the frequency meter circuit is being increased or decreased.
These clicks will approach each other as the coupling is loosened
until sufficiently loose coupling, giving only one click, is
found. This coupling should be used for the measurements. This
method can also be used with a receiving set not in the generating
condition by noting the sudden decrease of signal intensity as
the wavemeter is tuned to the frequency of the incoming signal.
To obtain accurate results it is necessary to use very loose
coupling.

     The zero beat method is the only one that is considered suf-
ficiently accurate for the most precise work. This method con-
sists of tuning a small electron-tube generator to the same fre-
quency as the incoming wave from the transmitting station, by
means of beats in a radio receiving set between the output of
the generating set and the incoming wave. When the frequency of
the beat note is zero, the frequency of the generator is then
exactly the same as that of the incoming standard wave. The fre-
quency meter is then tuned to resonance with the generator. The
frequency meter setting then corresponds exactly to the frequency
of the distant transmitting station. For details of the method,
see Part IV. If the frequency meter is a calibrated standard,
the station frequency is thus accurately determined. If, on the

other hand, the station frequency is of accurately known standard
value. (Bureau of Standards standard frequency transmissions or one
of the "constant frequency" or "standard frequency" stations), the
measurement yields a known frequency for calibration of the fre-
quency meter.

C. Requirements of Apparatus for Zero Beat Method.-As stated,
the method requires three pieces of apparatus, a receiving set, a
frequency meter, and a small radio-frequency generator. The re-
ceiving set may be any type capable of tuning to the required fre-
quencies; receiving set construction is not described in this cir-
cular. Desirable features of the whole assemblage of apparatus
are: accuracy, low cost, and the possibility of use of apparatus
that an experimenter may already have. A possible fourth require-
ment is that the apparatus be compact and portable.

Accuracy in the measurement of radio frequencies is of fun-
damental importance. To obtain it requires a properly constructed
frequency meter with a reliable calibration, and care and know-
ledge on the part of the observer. A careful compliance with the
instructions in this pamphlet will usually permit the obtaining
of an accuracy of a few tenths percent in the measurement of
radio frequencies. This estimated accuracy includes all devia-
tions in frequency which may occur between the primary source
from which the frequency meter is originally calibrated and the
final reading of the frequency from the calibration curves after
the frequency meter has been adjusted to another source of radio
frequency which is being measured. If the primary source of fre-
quency deviates by 0.2 percent from the absolute or true value of
frequency, then in order to be certain of an accuracy of say 0.5
per cent, the sum of all subsequent errors in calibration and ob-
servation must not be greater than 0.3 percent. This follows
because these errors might be either all positive or all negative;
if they were of opposite sign the accuracy of the particular
measurement would be better than 0.5 percent; in general, however,
the uncertainty of the measurement would be 0.5 percent.

Accuracy must not be confused with precision. Precision
refers to accidental deviations or errors in observation without
reference to the true values. It is possible to have precise
measurements and very poor accuracy. Both accuracy and precision
are likely to be greater when the frequency meter has a sensitive
resonance indicator. The relation between the sensitivity of
the resonance indicator and the power of the generator used are
discussed in Part II-c below.

General information on the principles of operation and cali-
bration of frequency meters is given in Bureau of Standards
Circular No.74, "Radio Instruments and Measurements," obtainable
from the Superintendent of Documents, Government Printing Office,
Washington, D.C., price sixty cents.

II. Frequency Meter

A. General Construction.-- Generally speaking, there are two
types of frequency meters, transmitting and receiving. Trans-
mitting frequency meters may in turn be divided into two general
classes, those which have buzzer excitation and those which have
electron tube excitation (the latter is usually called a hetero-
dyne frequency meter). The receiving type of frequency meter
only is considered in this circular. The transmitting type
which uses buzzer excitation does not permit of reliable measur-
urements. The heterodyne frequency meter is useful for ap-
proximate measurements and permits of precise adjustments, but
the variations introduced by changing the tube currents or
constants make it unsuitable for use as an accurate standard
unless recourse is had to very special design.

The usual receiving type of frequency meter consists
essentially of a coil of wire, a variable condenser and a reson-
ance indicating device to show when the instrument has been
properly adjusted to the source of radio-frequency power which
is being measured. By the substitution of various coils, the
frequency range is extended. It is also possible to obtain
measurements outside the range of the frequency meter by utiliz-
ing harmonics from a generator. (See Part IV, B and C, below).

A reliable frequency meter is usually not marked directly
in frequencies. Instead, an arbitrary reading is taken from an
engraved dial attached to the shaft of the condenser and the
value of the frequency is determined from a curve showing the
frequency corresponding to each setting of the condenser. This
curve is plotted from values obtained from a calibration of the
frequency meter (Part IV, B).

B. Mechanical and Electrical Requirements.-- The fundamental
requirement of a frequency meter, that it be capable of making
accurate measurements, largely determines its mechanical and
electrical design. It should be of such construction that it
will, with proper care and freedom from rough handling, maintain
its calibration over a considerable period of time. This re-
quires a minimum of variation in the inductance of the coils
and in the capacity of the condenser for any particular setting.
The general construction must be such that the parts and wiring
will not become displaced.

The requirement for the variable condenser, that its capa-
city remain constant for any particular dial setting, demands
detailed attention to its construction. Condensers other than
the rotating plate type should not be considered. Variable
condensers which employ an insulating material as a dielectric
are almost certain to undergo a change in capacity for any given
adjustment of the condenser dial. The plates should be of suf-
ficiently heavy material so that they will not become bent, and
they must be rigidly supported. A condenser giving close spacing
between the fixed and moving plates is undesirable because a

slight shifting in the position of the rotating shaft will produce an appreciable change in capacity. The bearings must have large wearing surfaces and they must be so designed that there is no end play in the shaft. The dial must be secured to the shaft in such a manner that there is no possibility of loosening. The condenser should have unimpeded rotation through 360 degrees as the use of stops is very likely to shift the position of the rotating plates.

In addition to the points discussed above, the requirement for accuracy in frequency meter construction demands consideration of three other features which relate to precision in its adjustment. These are (1) a condenser dial which will indicate small changes in adjustment; (2) means of eliminating the effect of body capacity and of obtaining a slow movement of the rotating plates; (3) a circuit of low radio-frequency resistance.

The condenser dial should be of metal engraved over one-half of its circumference with evenly spaced divisions which divide the dial into 100 equal parts or into 180 degrees. The lines should be sharply defined and of minimum width. In order to secure sufficient precision in setting the frequency meter condenser, it is necessary that the dial settings be read to a tenth of a division. This requires the use of a vernier scale.

The second requirement of precision in adjusting the frequency meter necessitates proper shielding and the use of a slow-motion device for the rotating plates. Shielding usually consists in mounting a metal sheet on the under side of the panel and connecting it to the rotating plates of the condenser. Shielding may also include lining the inside of the cabinet with metal. The slow-motion device may consist of a small knob geared to the shaft of the rotating plates. A simpler method of obtaining a fine adjustment of the condenser is to attach a light strip of wood about one foot in length to the condenser knob. This also eliminates body capacity, and shielding will probably not be necessary.

The third requirement for precision of the frequency meter, that it have low resistance, is necessary in order to obtain rapidly changing deflections of the resonance indicator with small changes in the condenser adjustment. The frequency meter will have a low resistance if its construction agrees with the points previously discussed, if the proper type of resonance indicator is used, and if the coils are wound with sufficiently large wire properly spaced. The resonance indicator and the coils are discussed in paragraphs C and D.

C. Resonance Indicator.-- If the experimenter has a frequency meter which he desires to use with equipment described in this circular, an examination of its construction should be made to see if it conforms to the requirements of accuracy discussed above. This examination may show the need for some alteration which may be made without the necessity of constructing a new frequency meter.

When the instrument is examined some derangement of the parts may occur which will affect its calibration. It is probable that a new calibration will be required in any case. (See Part IV, A).

In addition to an examination of the frequency meter, a test should be made to determine if it has sufficient precision for accurate measurements. To make this test, the instrument is coupled to a source of radio-frequency power so that good deflections of the resonance indicator are obtained. The frequency meter is now carefully tuned to resonance and the setting of the dial is recorded. The instrument is then detuned and again tuned to the same source of power, which has been kept at constant frequency, and another dial setting is recorded. This process is repeated until a number of readings are obtained. The frequencies corresponding with these various adjustments are then determined from the calibration curves, and the percentage difference between them is computed. If they agree within about 0.1 per cent it is an indication that the frequency meter is capable of making precise measurements.

The tests just described to determine the precision of a frequency meter equipped with the usual thermogalvanometer as a resonance indicator may show that it is suitable for measurements of frequencies from a high-power generator such as a radio transmitting set or a generator employing a tube of about five watts power. With the more sensitive type of resonance indicator described here and in more detail in Bureau of Standards Scientific Paper No.502, "An Improved Type of Wavemeter Resonance Indicator," a still less powerful generator, using dry batteries instead of storage batteries to supply the tube, is satisfactory. Descriptions of both types of generators are given in Part III.

The schematic wiring of the sensitive resonance indicating circuit is shown in Fig.1 and these parts are lettered to correspond to Fig.6 in Scientific Paper No.502. The essential parts of the resonance indicator are a crystal detector D and a sensitive direct-current milliammeter MA giving full-scale deflection with not more than 1 or 2 milliamperes. Undoubtedly, the use of a crystal detector will seem objectionable to many persons. It has been found, however, that if a detector of substantial mechanical design which is equipped with a good galena crystal is used, no difficulty is experienced in maintaining a sensitive adjustment.

The first step in the application of the resonance indicator is to short-circuit the old resonance indicating device by a heavy conductor (Z, Fig.1) firmly clamped or soldered in place. Reference should now be made to Scientific Paper No.502 for details of wiring. The sensitivity of this resonance indicator is largely determined by the size and number of turns of the coil L', Fig.1, (Fig.6, Scientific Paper No.502). This coil is used in a frequency meter for measurements with a radio-frequency generator employing an electron tube of about five watts power. If the frequency meter is to be used with a low-power generator as described in this circular, L' will consist of more turns, determined experimentally in the tests described below. Due to different

types of frequency meter construction, some variations in the con-
nections of this resonance indicating circuit may be required for
best results. For this reason, connections may be temporarily
made, and the test described below will indicate if the circuit
is in proper working condition. The connections should then be
rigidly and permanently made.

        The most satisfactory test of the resonance indicator is
made by means of a low-power generator such as described in
Part III. In place of this, a radio transmitting set may be used.
However, this will not be as satisfactory because there will be
no way of determining if the resonance indicator is sufficiently
sensitive for use with a low-power generator. The frequency meter
is coupled to the generator which is adjusted to a frequency cor-
responding to the lowest setting of the frequency meter condenser
when using the smallest coil. With a low-power generator the re-
spective coils of the generator and frequency meter should be
separated by about six or eight inches. Closer coupling will
probably produce a reactive effect which will prevent precise
measurements. It may happen that the generator is of such low
power that a change in coupling will affect the setting of the
frequency meter. This condition may usually be overcome by employ-
ing a higher plate voltage for the tube used in the generator. If
a source of high power is used, very loose coupling must be em-
ployed.

        The crystal detector is adjusted to a sensitive condition
and the frequency meter is tuned to resonance with the generator
by noting the maximum deflection of the milliammeter. With the
coupling specified above for a low-power generator, the resonance
deflection of the milliammeter should not be greater than about
one-third the total range of the scale. This deflection may be
secured by varying the number of turns of L'. The generator is
now adjusted to a frequency corresponding to approximately the
highest setting of the frequency meter, and the latter is again
tuned to resonance so that a maximum deflection of the milliam-
meter is obtained. These two deflections should be made as
nearly as possible the same. This may be done by shifting the
one-point connection from X to E or F, Fig.1. Greater deflections
may of course be obtained by using increased coupling, but if the
coupling is too close the reactive effect will spoil the precision
of the measurement. With the proper amount of coupling to the
generator, greater resonance deflections may also be obtained by
the use of more turns of wire on the coil L'. Fig.1. If the num-
ber of turns of this coil is too great, it will absorb so much
power from the frequency meter circuit that a readjustment of the
crystal detector will spoil the calibration. Tests should be made
to determine if this effect is in evidence.

        This effect is most pronounced at the high-frequency adjust-
ments. Therefore, the frequency meter condenser should be adjust-
ed near minimum capacity with the coil of the smallest inductance.
The generator is tuned approximately to resonance, the frequency
meter is tuned very carefully to the exact resonance point, and
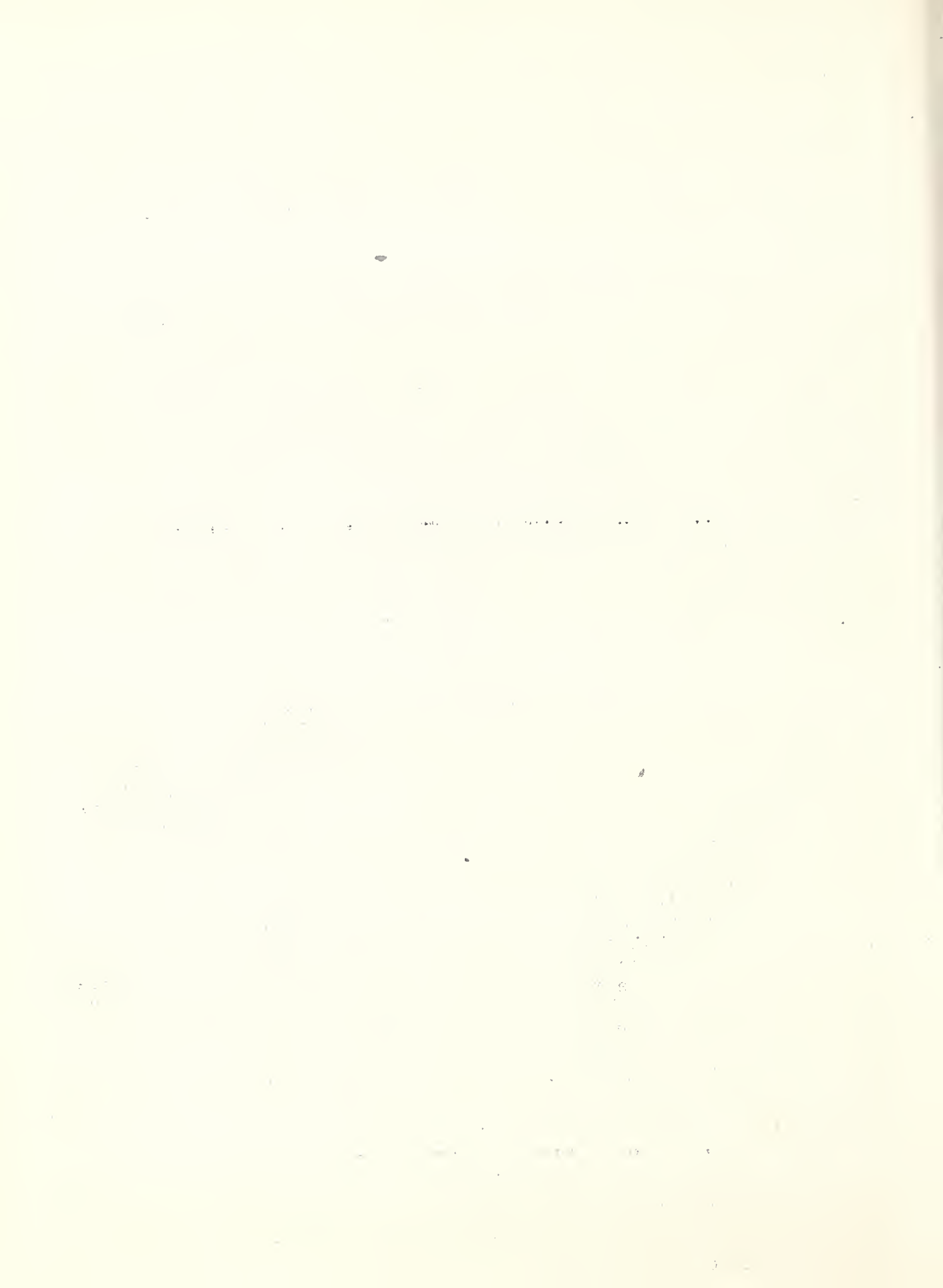
the setting of the condenser dial is recorded. The crystal de-
tector is then readjusted so that the resonance deflection is
reduced about one-third. The frequency meter is again tuned, and
a second reading of the condenser dial is taken. If several repe-
titions of these tests indicate that the adjustment of the crystal
detector produces an appreciable change in the setting of the fre-
quency meter dial (corresponding to frequency differences of more
than about 0.1 per cent), then it is an indication that too many
turns are used on coil L' in the resonance indicating circuit,
Fig.1. Reducing the number of turns of this coil may reduce the
resonance deflections of the milliammeter at the low-frequency
adjustments to such an extent that a precise setting of the fre-
quency meter condenser can not be obtained from a low-power gen-
erator. In this case a metal plate B, Fig.1, connected in the
resonance indicating circuit may be used to secure somewhat larger
deflections which do not give changed settings in the condenser
upon readjusting the crystal. This plate is mounted inside the
frequency meter case near the plates of the condenser which are
not connected to the shield and should have an area of about six
or eight square inches.

        If the milliammeter is not provided with internal damping,
a damping resistance should be connected across its terminals.
The most satisfactory value of this resistance would, as far as
securing stability of the needle is concerned, be the critical
damping resistance of this instrument. However, in order to
insure a satisfactory sensitivity this resistance should be suf-
ficiently high so as not to reduce the normal deflection of the
milliammeter by more than about one-third.

        D. Construction of Simple Frequency Meter.--In the specifi-
cations for the construction of a frequency meter given below, it
is assumed that there is an agreement with all the requirements
of accuracy discussed under Part II, B. The description given
below is principally devoted to details of construction applic-
able to this particular frequency meter, which will cover a fre-
quency range from about 500 to 3000 kc (345 to 100 meters). Ac-
curate measurements of considerably higher frequencies may be
obtained by the use of harmonics.

        The essential parts of the frequency meter are: two coils,
a variable condenser, a resonance indicator, a panel of insulat-
ing material and a cabinet. The general appearance of the com-
pleted instrument is shown in Fig.2. The coils are made by wind-
ing wire on wooden forms 4 inches in diameter and having a wind-
ing space of 7/8 inch. Two brass strips are attached to each
coil form to permit the substitution of either coil in the cir-
cuit by inserting their slotted ends under binding posts mounted
on the panel. The terminals of the coil are connected to the
brass strips. The wood for the coil forms must be well seasoned
and should be protected from moisture by a good grade of varnish.
Instead of using the round coil forms, each form may be built up
of a block of wood 7/8 inch thick and 4 inches square which is
placed between two thin squares of wood of somewhat larger dimen-
sions so as to form a shallow groove or winding space. The
corners of the blocks should be rounded.

--The inductance of the coils must be such that the specified
range of frequencies will be covered with a variable condenser
having a maximum capacity of 0.001 microfarad. This inductance is
determined principally by the size and shape of the coil form, the
number of turns and the spacing between turns. A fairly reliable
capacity rating of the condenser is specified by the manufacturer.
Since the frequency meter is required to cover a given range,
(550 - 3000 kc), allowances must be made for slight deviations in
the inductance of the coils and the capacity of the condenser from
the required values. The data given in Table I considers these
deviations and if adhered to, the desired frequency range of the
frequency meter will be secured, together with a sufficient
"overlap" between the coils. Larger wire is used on coil 2 in
order to reduce the resistance at the higher frequencies.

Table I.
Coils for Frequency Meter

Maximum capacity of variable condenser— microfarads.	Coil 1 - 7/8 inch winding space. Range 550 to 1500 kc.		Coil 2 - 7/8 inch winding space. Range 1400 to 3000 kc.	
	Round form (4 inches dia.)	Square form (3 3/4 in. square)	Round form (4 inches dia.)	Square form (3 3/4 in. square)
0.001	One closely wound layer No.22 AWG d.c.c. wire.		10 turns No.30 AWG d.c.c.wire evenly spaced.	

The coil terminals are brought out through small holes in the
winding form and soldered to the brass connection strips. The
turns must be protected from moisture by the proper application
of varnish. Only varnishes of the best quality, especially made
for electrical insulation purposes, should be employed. Even if
this precaution in the selection of the varnish is taken, it fre-
quently happens that as the varnish ages, the inductance of the
coil changes appreciably. To partially overcome this difficulty,
the varnish should be applied sparingly. In no case should an
attempt be made to impregnate the coil.

The turns of the coil must be protected from mechanical
injury and displacement. In the case of the round coil forms
this may be accomplished by wrapping strips of celluloid around
the edges, or if square forms are used, thin strips of wood may
be secured to the edges.

The panel upon which the parts are mounted must be made of a piece of insulating material of sufficient thickness to insure rigidity. It is fitted into a cabinet of suitable size, approximate dimensions being indicated in Fig.2. These dimensions will, of course, vary somewhat with the size of the parts. The illustration suggests dimensions of sufficient size to provide a separate compartment for storing the coils and the milliammeter. Provision should be made for the elimination of shock to these parts and the compartment should be provided with a separate cover which is readily removable.

After the panel is drilled in accordance with the requirements for mounting the parts and binding posts, the lower side of this panel should be shielded. For this purpose a sheet of thin brass or copper is satisfactory. The shield is connected to the rotating condenser plates. It must be carefully cut away so that no contact is made with the binding posts, wiring, or other parts of the circuit except where these parts are themselves connected to the rotating condenser plates.

The schematic wiring of the frequency meter is shown in Fig.1. The wiring must be made with great care so that permanently rigid connections will result. The condenser C and coil L form the resonance circuit, the wiring of which merely consists in running two rigid leads from the terminals of the variable condenser to the binding posts where the coils are to be connected. The parts of the resonance indicating circuit should be temporarily wired together, and tests made to determine a satisfactory operating condition, as previously described under Part II, C. The wiring is then permanently and rigidly made.

In case it is desired to use a variable air condenser which is shielded and already calibrated in terms of capacity, as the condenser in the frequency meter, it may be considered undesirable to open the condenser in order to attach the coil L' and plate B of Fig.1. In this case the resonance indicating device indicated in Fig.1 may be modified somewhat and satisfactory results obtained. Plate B may be omitted and coil L' consist of two or three turns of No.10 or 12 A.W.G. copper wire mounted outside the frequency meter cabinet. The coil L' should have approximately the same diameter as coil L and be firmly fastened in the position in which it is calibrated. It may be within 2 or 3 inches of coil L and should be mounted so as to be least in that way.

E. Care of Frequency Meter.--In following the instructions for the construction and use of radi -frequency measuring equipment given in this circular, it must be understood that the calibration of the frequency meter is not permanent. Proper care of the instrument, such as avoiding mechanical shock and exposing it to sunlight, or more especially, to dampness will be of assistance in maintaining the calibration. However, after a period of a few months, particularly when the frequency meter is

new, it is necessary to obtain a check of its calibration (method
given in PartIV,A, below). In case this shows a change of more
than about 0.2 per cent, a new calibration should be made.

As a suggestion for checking the calibration it will usually
be sufficient to obtain three or four points for each curve, pro-
vided these points are so located that two of them lie near the
ends of the curve and that the other points are approximately
uniformly spaced. In obtaining a check in this manner the source
of the primary frequencies must be known to be accurate, other-
wise it may appear that the calibration of the frequency meter
is inaccurate, when, as a matter of fact, the inaccuracy is due
to the points used for checking. If these points lie at appre-
ciably different distances from the curve, then it is probable
that the frequency meter calibration has changed and a complete
new calibration should be obtained. It may happen that these
points all lie upon one side of the curve at the same distance
from it. In this case, assuming that the points have been care-
fully taken from an accurate frequency source, it is permissible
to draw a new curve through them and parallel to the old curve.
This amounts to a recalibration of the frequency meter without
the necessity of obtaining many new frequency points.

III. Generator.

A. Requirements.--A generator of radio-frequency currents
consists essentially of a coil of wire, a variable condenser, and
an electron tube. The inductance of the coil and the capacity
to which the condenser is adjusted practically determine the
generated frequency. The frequency range of the generator is
extended by the substitution of coils of different inductance.
A fundamental requirement of a generator when used in conjunction
with a frequency meter and radio receiving set, as described later,
is that it be of sufficient power to permit precise adjustments
of the frequency meter. The latter device when equipped with
the type of resonance indicator previously described permits
the use of a low-power generator having an electron tube operated
by dry batteries. If the frequency meter is equipped with the
usual type of resonance indicator it is probable that a generator
employing a tube of about 5 watts power will be required. The two
types of generators are described in B and C below. Those persons
who have access to a machine shop and who desire a generator of
finished construction are referred to Bureau of Standards Letter
Circular No.187, "Specifications for portable auxiliary generator,
Bureau of Standards Type O," which may be obtained upon request.
Other requirements of the generator are that it be capable of
gradual frequency variation, that it be simple in operation, and
that it maintain a constant frequency, for a particular adjust-
ment during the time interval required for a measurement.

B. Construction of Low-Power Generator.--The cost of this
generator is much less than that of a frequency meter. The
schematic wiring, utilizing the well-known Hartley circuit, is
shown in Fig.3, and the general appearance of the completed gen-
erator is shown in Fig.4. Variations in the inductance of the

coils and in the capacity of the condenser for a particular setting over any except a short time interval are of no consequence. Hence the precautions necessary to secure constancy as prescribed for the wavemeter are not necessary. For the uses to be described the required frequency range of the generator should be approximately 300 to 3000 kc. This is obtained by two coils and a variable condenser of 0.001 microfarad capacity.

The generator cabinet accommodates the dry cell A and B batteries and provides storage space for the coils. The variable condenser, tube socket, and rheostat are mounted on the under side of a wooden panel. A panel of insulating material may be used but it is not necessary. The arrangement of the parts on the panel as suggested in Fig.4 permits short connecting wires and provides space inside the cabinet for batteries. The electron tube used should be of a type which may be operated on dry cell A batteries requiring a small amount of space. The B battery should consist of at least three 22 1/2-volt units and if the dimensions of the cabinet are as shown in Fig.4, the small size battery unit is required. Although these suggestions for the A and B batteries are given with the idea of using a small amount of space in order that the apparatus may be most readily transported, it will, in general be more satisfactory to employ a high plate voltage on the tube, and this will probably require the use of more B batteries which can not be mounted inside the generator cabinet having the dimensions shown in Fig.4. The use of higher plate voltages increases the power of the generator so that looser coupling may be employed between the generator and frequency meter. Thus the use of more plate batteries while rendering the equipment somewhat less portable, has the advantage of requiring fewer precautions in the measurements.

The generator coils are of the so-called spiderweb type, as shown in Fig.4. This type of coil is easily wound to an approximate required inductance since it does not require the selection of a cylindrical winding form of a given diameter. It also has the advantage of compactness. On the other hand, it is probable that single-layer coils wound on cylindrical forms will give slightly better results. The two terminals of each coil are anchored to the cardboard form and allowed to project about six inches. A third terminal is formed by soldering a wire to a point near the center of the coil. The three terminals are connected to binding posts on the generator panel.

The variable condenser used in the generator should have a maximum capacity of 0.001 microfarad. This determines the specifications for the coils as shown in Table II in order that the generator may cover the required range of frequencies (approximately 300 to 3000 kc) with sufficient overlap between coils. The coils are wound with No.20 or 22 AWG d.c.c. wire upon cardboard forms having an odd number of projections or spokes.

Table II
Coils for Low-Power Radio-Frequency Generator.

Coil No.	1 (Range 300 to 1400 kc)	2 (Range 800 to 3000 kc)
Approximate out-side diameter of flat coil form.	6 1/4 inches	6 inches
Inside diameter of flat coil form.	3 inches	3 inches
Number of turns	50 - No.22 AWG d.c.c.wire	30 - No.20 d.c.c. wire.

The condenser should be provided with a dial and a type of knob which will permit attaching a light wooden strip about 14 inches in length. This will allow adjusting the condenser without any appreciable capacity effect from the body of the observer, a necessary condition for precise adjustments. This method of adjusting the condenser eliminates the necessity of shielding.

The schematic wiring of the generator is shown in Fig.3. Insulated wires are brought out from the batteries and connected to the proper binding posts on the panel which is then secured in position. The batteries are held in place inside the cabinet by wooden strips. The headphones are connected to the proper binding posts, the rheostat turned on, and the coil terminal which leads to the grid of the tube is tapped lightly with a moistened finger, while the condenser is rotated. A succession of clicks shows that the circuit is in a generating condition.

C. Construction of Five-Watt Generator.- To operate a fre-quency meter equipped with the usual thermogalvanometer as a reso-nance indicator, the generator described above will probably not prove sufficiently powerful. Greater power can be obtained by using a generator of somewhat different construction employing a five-watt tube, the connections being made as shown in Fig.5. Inductor "B" is a 5 3/4 inch tube of suitable insulating material about 9 inches long, wound with 200 turns of No.22 B&S gauge double cotton covered copper wire. Taps are made on turns as shown. This coil is used for frequencies from 100 to 1000 kilocycles. Inductor "A" consists of 55 turns of No.16 B&S gauge double cotton covered copper wire on a tube about $3\frac{1}{2}$ inches in diameter and about $4\frac{1}{2}$ inches long. Taps are taken off at every fifth turn. This coil is used for frequencies from 500 to 2000 kilocycles. The plate voltage may be secured from several $22\frac{1}{2}$ volt "B" batteries con-nected in series to give a voltage of from about 100 to 400 volts. It is desirable to completely shield the generator by placing it in a box lined with copper window screening which should be grounded. A long handle should be attached to the variable con-denser control to obtain fine adjustment and reduce body capacity effects.

IV. Measurement Procedure.

As previously stated, the measurement of a station frequency
may be either for the purpose of finding out that frequency value
or for the purpose of using it to calibrate some apparatus (usually
a frequency meter). The procedure is somewhat different with the
two objectives. The use of such measurement to calibrate apparatus
from known station frequencies is dealt with first. However, in
calibrating a frequency meter, the auxiliary apparatus required
(generator and receiving set) is the same as for the purpose of
determining the values of frequencies of distant transmitting
stations. Section A on frequency meter calibration necessarily
therefore gives considerable of the technique of the other process.

A. Frequency Meter Calibration.- The calibration requires the
use of radio signals of known standard frequency. These, as alrea
stated, may be either the standard frequency signals of the Bureau
of Standards or the "standard frequency" or "constant frequency"
stations (listed monthly in the Radio Service Bulletin).

In arranging the apparatus for receiving signals for fre-
quency meter calibration, the generator should be placed between
the frequency meter and the receiving set so that coupling will be
obtained between them. This also gives coupling between the gen-
erator and the frequency meter. Very loose coupling is required
between the receiving set and the generator; they should be so far
apart that there is no danger of the generator blocking the detec-
tor tube of the receiving set.

The method of obtaining a frequency meter calibration from
the known frequencies of distant stations consist in obtaining
points on the frequency meter corresponding to those frequencies
and obtaining additional points by utilizing harmonics from the
local generator. This method gives a sufficient number of points
to permit the plotting of reliable calibration curves. As many
primary frequencies as possible should be obtained. If this is
done, time will be saved by a reduction in the number of harmonics
which will be required, and errors in calibration which might be
caused by the deviation of a primary frequency will be largely
eliminated. On the other hand, it is possible by the use of har-
monics to obtain a complete frequency meter calibration from a
single known frequency. If it is desired to check a calibration
previously obtained rather than to obtain a new calibration, the
signals of known frequency will often be sufficient without the
necessity of employing harmonics from the local generator.

The method of obtaining known frequencies for the calibra-
tion employs the principle of zero beat and permits of a high
degree of precision. If an unmodulated frequency is being
received it will be most convenient to first adjust the
receiving set to the point of self-generation. If a non-
generating receiving set is used, it is necessary to tune it

approximately to the transmitting station and then adjust the
generator until an audible beat note is produced in the phones of
the receiving set. Retuning the receiving set slightly will pro-
duce a beat note of maximum intensity. If a broadcasting station
is being received, the set is tuned to maximum signal, but is not
adjusted to a generating condition. The generator is then tuned
until it produces an audible beat note with the incoming carrier
frequency.

When the desired transmitting station has been tuned in on
the receiving set, the local generator must be adjusted to a con-
dition of zero beat while the receiving set is in a non-generating
condition. This adjustment transfers the frequency of the distant
station to the local generator. It must be made with great care
so that the error in setting will be small. The observer should
place himself in such a position that the body capacity will not
affect the adjustments of the frequency meter and generator. An
extremely precise adjustment of the generator may be obtained by
tapping a pointer attached to the knob of the condenser. The
frequency meter is now carefully tuned until the resonance indi-
cator shows a maximum deflection. As it is tuned near the point
of resonance, the reactive effect may cause a slight variation in
the frequency of the generator, with the result that the beat
note will again be heard. This change may be measurable on the
frequency meter and therefore adjustments should be made to again
attain the condition of zero beat. This may require decreased
coupling between the frequency meter and the generator in addition
to a slight readjustment of the generator. The coupling should at
all times be kept as loose as possible consistent with obtaining
precise adjustments of the frequency meter. To reduce the errors
in observation as much as possible a number of successive readings
of the frequency meter should be taken, the generator being of
course always kept at the adjustment corresponding to zero beat.
In general, the mean value of these readings will be most reliable.
In case one of these readings shows a comparatively great devia-
tion from the mean value, all the readings are doubtful and should
be discarded.

A special method of adjusting the frequency meter may be used
to secure increased precision. The instrument is first adjusted
as near as possible to resonance. If the generator frequency is
now lowered, for example, 500 cycles, the resonance indicator
reading will decrease. Then if the frequency is increased above
zero beat by the same amount (500 cycles), the reading of the
resonance indicator should increase to maximum as zero beat is
passed and then decrease to the same value as was obtained at the
frequency of 500 cycles below zero beat. In other words owing
to the symmetrical shape of the resonance curve of the frequency
meter, the resonance indicator readings should be the same for
frequencies above and below the resonance frequency by the same
amount.

B. Use of Harmonics.- Having determined as many known fre-
quency points as possible, the method of harmonics is used to
obtain additional points over the range of the frequency meter.
This method as described below is not intended to be inclusive,
that is, it does not give in detail the obtaining of all the
points necessary for plotting calibration curves. By following
through the method as described, the experimenter will gain a
sufficient idea of the process to enable him to vary it slightly
according to the apparatus which is at hand. For this work,
two generators, which may be of the type previously described,
are required. A receiving set which can be adjusted to a gen-
erating condition, or the circuit of a continuous wave trans-
mitter in the room where the apparatus is located, may serve as
one of the generators. To obtain stronger harmonics it is
sometimes desirable to increase the plate voltage above the
normal value and to somewhat reduce the filament current. Head-
phones are inserted in the plate circuit of one of the generators.
In using the method of harmonics, it is important to be able to
readily determine the harmonic which is employed to obtain zero
beat. To this end, it is very desirable to have an approximate
calibration of the generator so that an idea of the frequency to
which it is adjusted may be obtained by noting the condenser
setting and the particular coil which is used. If the generator
is constructed as previously described, the approximate frequency
to which it is adjusted may be estimated from the dial setting.

The calibration by harmonics should preferably be started
at the same time a signal of known frequency is being received.
This will permit setting the generator to zero beat with the
incoming signal. If the known frequency has been previously trans-
ferred to the frequency meter, the generator may be adjusted to
this frequency by tuning to resonance with the frequency meter.
The signal frequency is thus reproduced in the generator instead
of the generator being directly adjusted to the incoming signal,
and therefore the observational error is increased. After adjust-
ing the generator to the known frequency, precautions should be
taken to see that the frequency of the generator remains constant.
This may be determined by noting the constancy of the pitch of
the beat note obtained by reaction with a second generator.
Fig.5 shows graphically the method of obtaining harmonics between
generators. Assume that a frequency of 600 kilocycles is being
received. Having set generator A to 600 kilocycles, generator B
is tuned to the same frequency by zero beat. In order to deter-
mine that this beat is produced by the fundamental frequencies
of the two generators, the settings of the condensers may be
noted and (assuming that the generators are of similar construc-
tion) will be found to be approximately the same, or the frequency
meter may be used to indicate that the beat note produced between
the two generators comes from their fundamental frequencies. The
condenser of generator B is now reduced to about 1/4 its scale
setting until a second beat note is heard. This beat is caused
by the second harmonic of generator A (1200 kc) reacting with the
new fundamental frequency of generator B. The frequency meter
is now carefully tuned to resonance with generator B, and a number
of readings are taken to reduce the errors in observation. The
1200-kilocycle frequency point thus obtained is recorded.

By the substitution of a different coil the frequency of generator B is again increased until another beat note is obtained. This is caused by the third harmonic (1800 kc) of generator A beating with the fundamental of B. It is transferred to the frequency meter in the same manner as before. Leaving generator B adjusted to 1800 kc, the frequency of generator A is increased until another zero beat note is obtained. This is the second harmonic of generator A (fundamental now 900 kc) beating with the fundamental frequency (1800 kc) of generator B. This is transferred to the frequency meter. Generator A is now left at the 900-kilocycle adjustment, and the frequency of generator B is increased to 2700 kc producing zero beat with the third harmonic of A. The frequency of 2700 kc is then transferred to the frequency meter. Harmonics from other primary frequencies are obtained in the same manner.

Of equal importance to obtaining accurate frequency points is the plotting of these points on cross-section paper so that a smooth curve may be drawn between them permitting the accurate determination of frequencies corresponding to any setting of the frequency meter dial. Curves obtained for the frequency meter described in this circular are shown in Figs. 7a and 7b. These curves are merely illustrative, and it is not to be presumed that they are accurate. The mimeograph process of reproduction does not permit showing accurate curves here.

Assuming that the observations are accurate, the more points obtained for the plotting of curves, the better. If in attempting to draw a smooth curve through the points, some of them appear to lie to one side, then these points usually indicate observational errors, and it is best to repeat the observations. However, it sometimes happens that in drawing a curve only a few of the points will lie slightly outside of its path. In this case a "mean" curve should be drawn, that is, a smooth curve so located that these points will lie equally on each side. Accuracy in the use of calibration curves depends to a considerable extent upon the scales chosen for locating the points. The scales for these curves should be chosen sufficiently large so that any errors in plotting the points or in reading the frequency from the curve after the points have been plotted will be less than the observational errors in making measurements. To illustrate, reference may be made to the frequency meter dial. The vernier scale suggested for this dial permits reading to 0.1 of a division and estimating to about 0.05 of a division. Therefore, the points for the frequency meter scale (located on the horizontal axis) should be plotted to such a scale on the cross-section paper that they may be readily located to within 0.02 or 0.03 of a division of the frequency meter dial. As a second illustration, reference may be made to the frequency points as located on the vertical axis. It has been previously assumed that by following the specifications for frequency meter construction and operation, an accuracy of better than 0.5 per cent may be obtained. Therefore the scale of frequencies is to be so chosen that the points may be laid off to an accuracy considerably greater than 0.5 per cent, say one or two tenths per cent.

This discussion relative to the scales used in plotting curves must be given with a word of caution. While it is true that in order to eliminate or reduce the errors in reading frequencies from the curves, the scales should be chosen so that these errors are less than any errors which may be made in the observations, it is also true that one can not expect to obtain a more accurate value of frequency from these curves than is possible to obtain by the actual calibration of the frequency meter. For instance, suppose that a certain dial setting on the frequency meter shows from the completed curve that the corresponding frequency is 500.5 kc. The value of 0.5 kc represents a discrimination of 0.5 part in 500 which is equivalent to 0.1 per cent. Since, however, the accuracy of the frequency meter calibration may not be better than 0.5 per cent, the frequency as chosen from the curve will be recorded as either 500 or 501 kc.

C. Measurement of Frequency of a Station.- In the preceding discussion (Sec.A) giving methods of calibrating a frequency meter, its use as a measuring instrument is necessarily described to a considerable extent. This is particularly true in regard to precautions to be taken in the measurements so that the observational errors will be a minimum. However, the discussion below adds something to the procedure of frequency measurements previously given by describing specifically the determination of station frequencies. In following these instructions careful consideration should be given to the precautions previously discussed.

First, there is the measurement of a distant transmitting station of a frequency within the range of the frequency meter. This operation is essentially the same as locating a point from a transmitting station when the frequency meter was calibrated. After the generator is tuned to zero beat with the incoming signal, the frequency meter is tuned to the generator, the setting of the frequency meter is read, and the frequency is obtained from the calibration curves.

A second kind of measurement of a distant transmitting station is sometimes desired when the frequency of this station is higher than that which may be directly measured. In this case the generator is tuned to zero beat with the incoming frequency, the zero beat being produced by a harmonic of the generator combining with the received frequency. The generator fundamental frequency is then measured as previously described, and it is merely necessary to determine the harmonic of the generator which was used in setting to zero beat.

The reader is also reminded that the "resonance click method," described in Part I-B, may be used for less accurate measurement of frequency of a station.
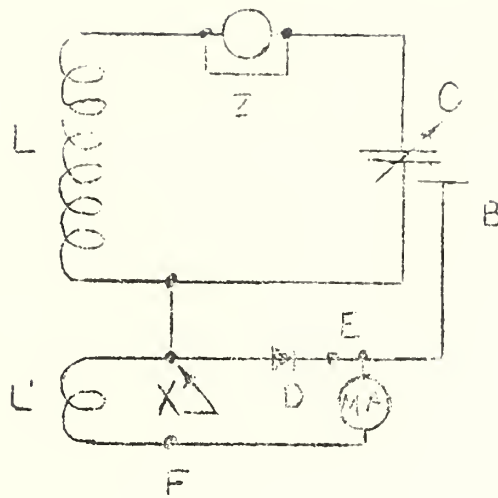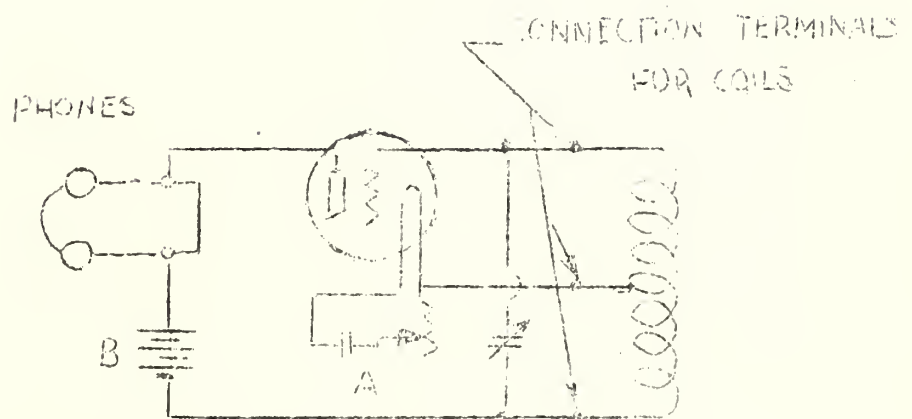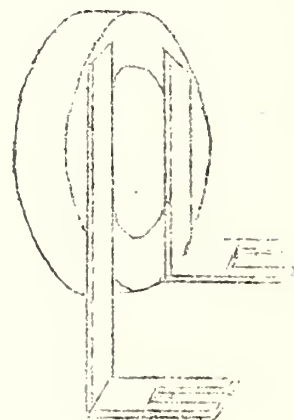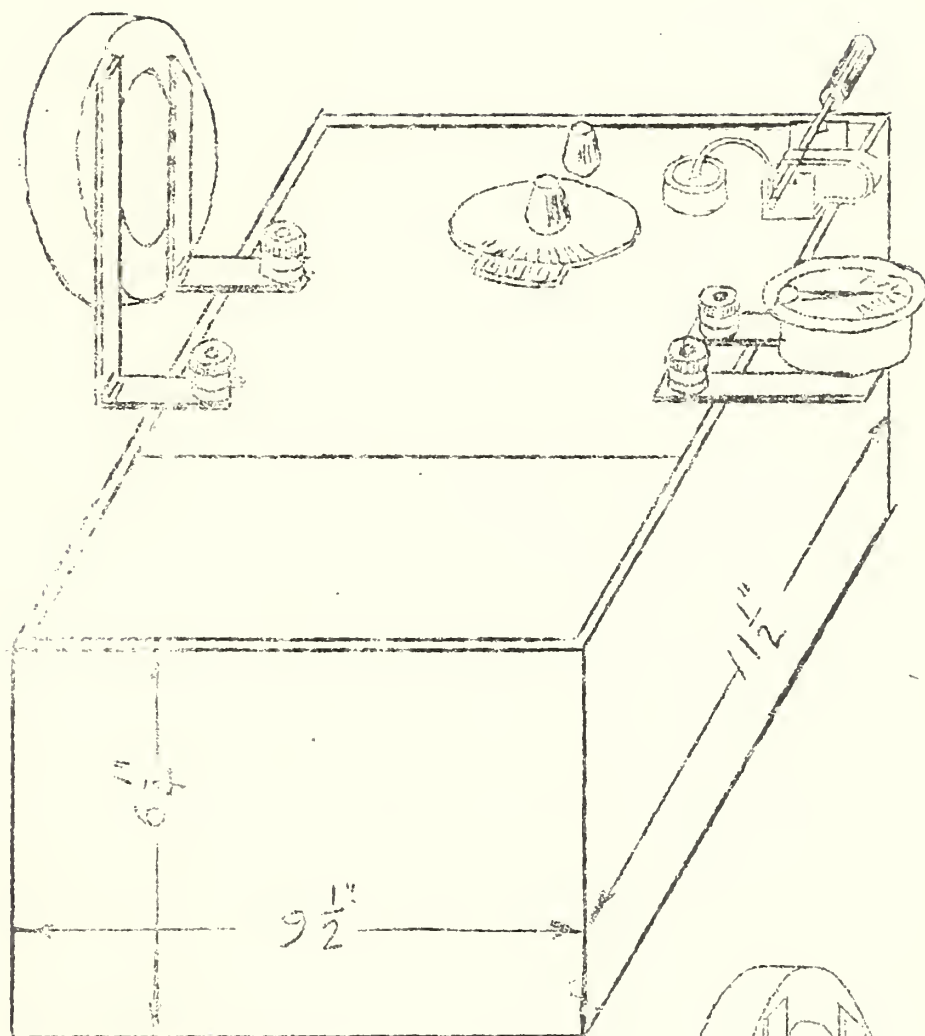

Attached:
    Figs.1,2,3,4,5,6,7a,7b.

FIG 1

PHONES

CONNECTION TERMINALS
FOR COILS

FIG. 3

$1\frac{1}{2}''$

$6\frac{1}{4}''$

$9\frac{1}{2}''$

FIG 2

FIG. 4.

Inductor A

Turns

Turns

Inductor B

Turns

30

15 Taps

15

15

15

15

10

10

15

15

15

15

30

100 to 400
volts, d.c.

1-microfarad

5-watt tube

0.001 microfarad
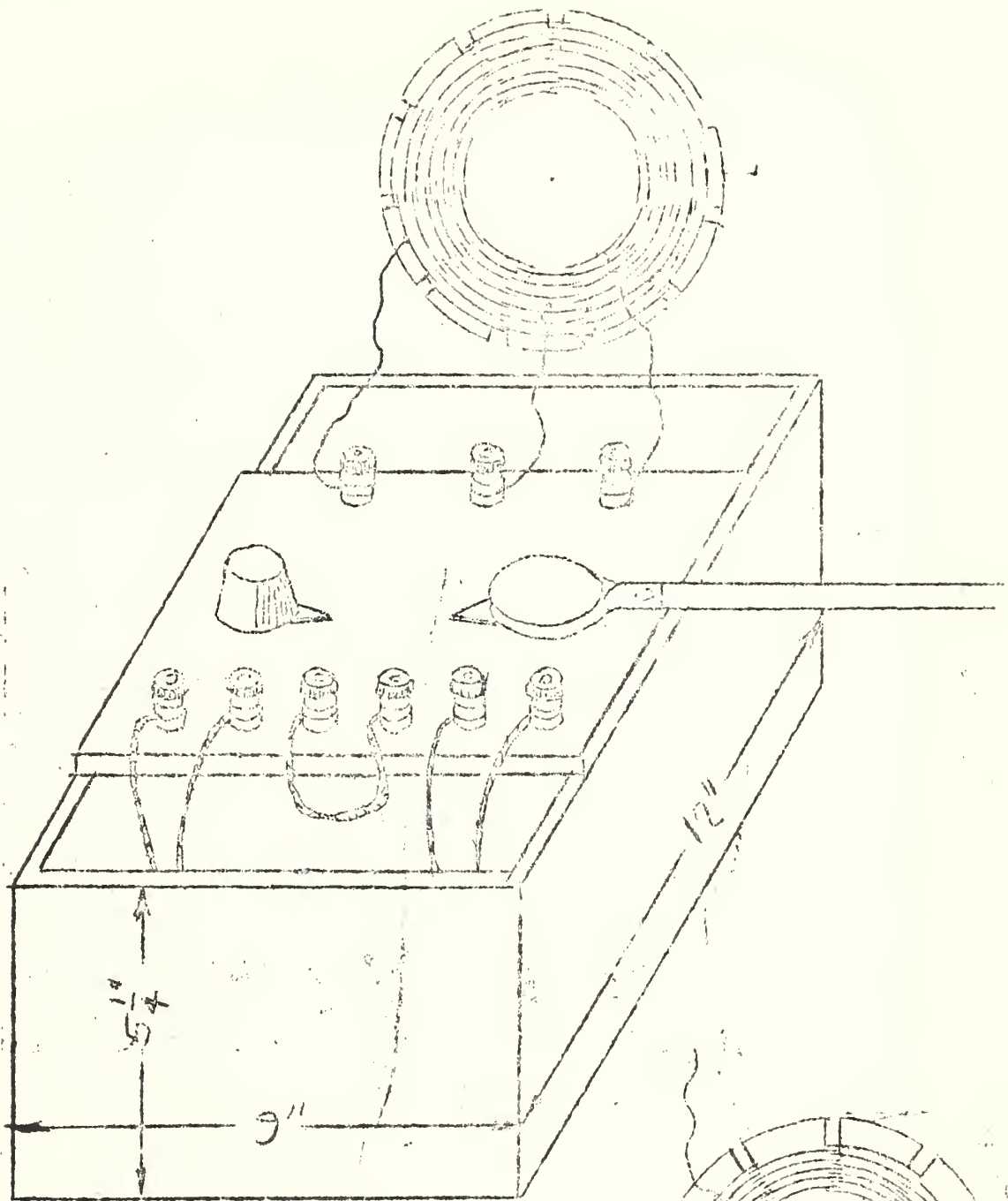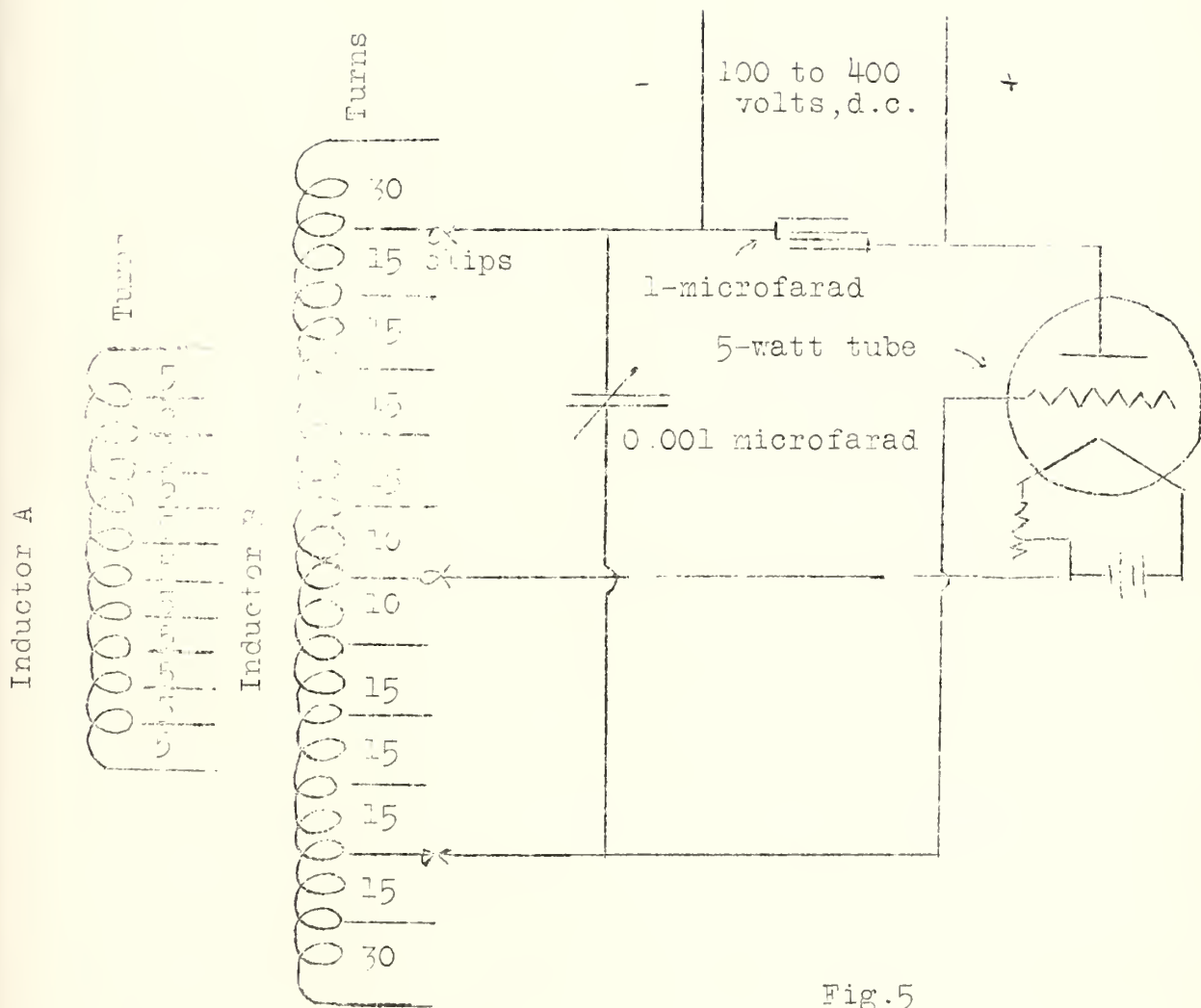
Fig.5

Wavemeter
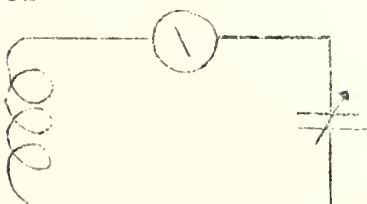
(PRIMARY
FREQUENCY
OF 600
KILOCYCLES)

GENERATOR
A.

GENERATOR
B

FREQUENCY
METER

RECEIVING
SET
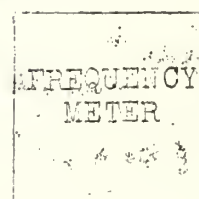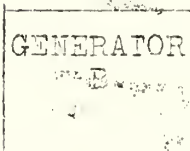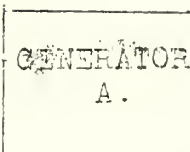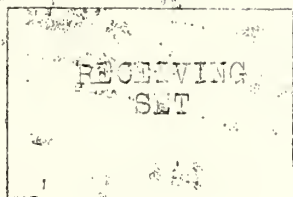
ADJUST A TO 600 KC -- TRANSFER TO FREQUENCY METER.
   "   B   1200 KC   "   "   "   "
   "   B   1800 KC   "   "   "   "

LEAVE B AT 1800 KC
ADJUST A TO 900 KC --   "   "   "   "

LEAVE A AT 900 KC
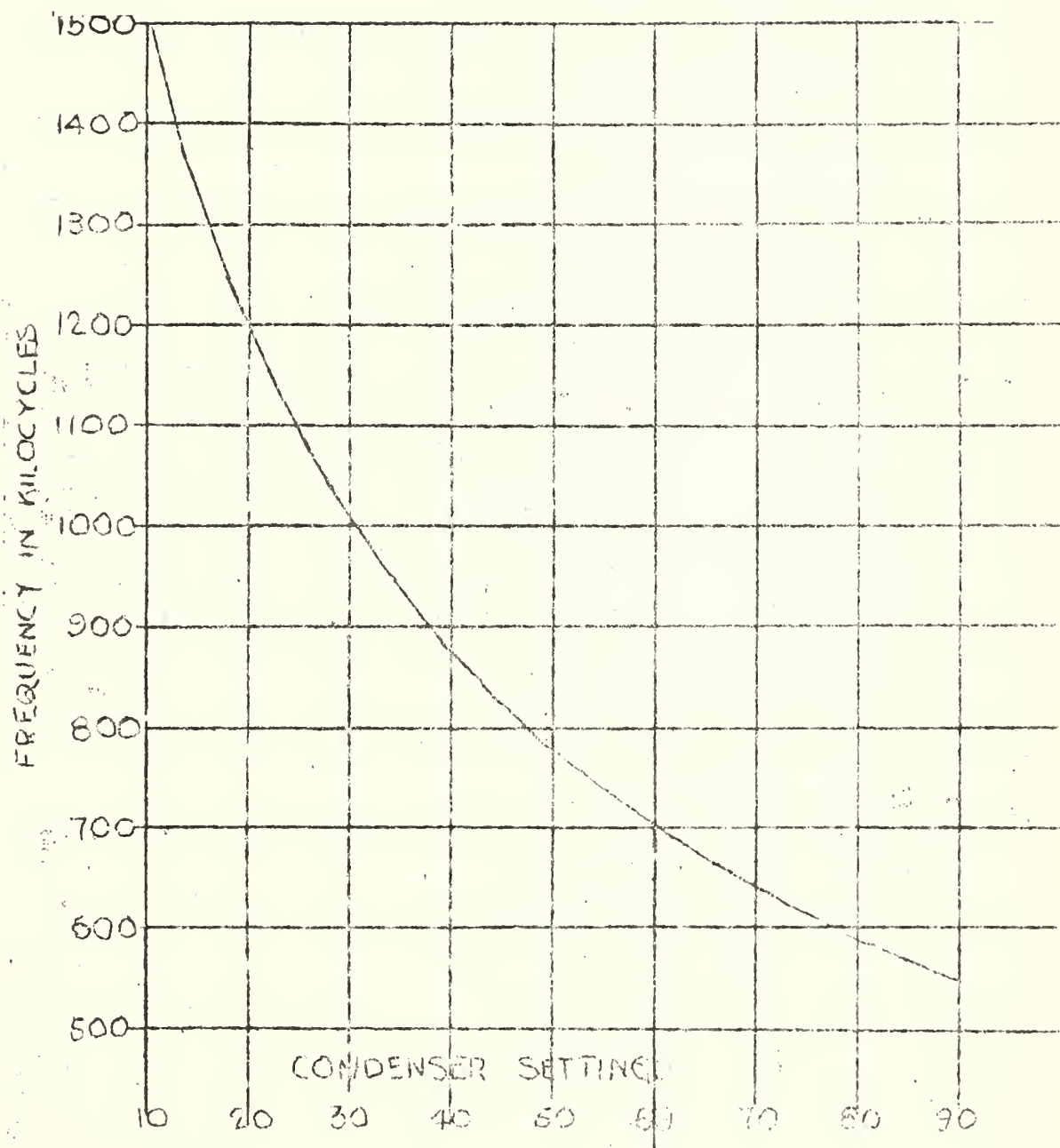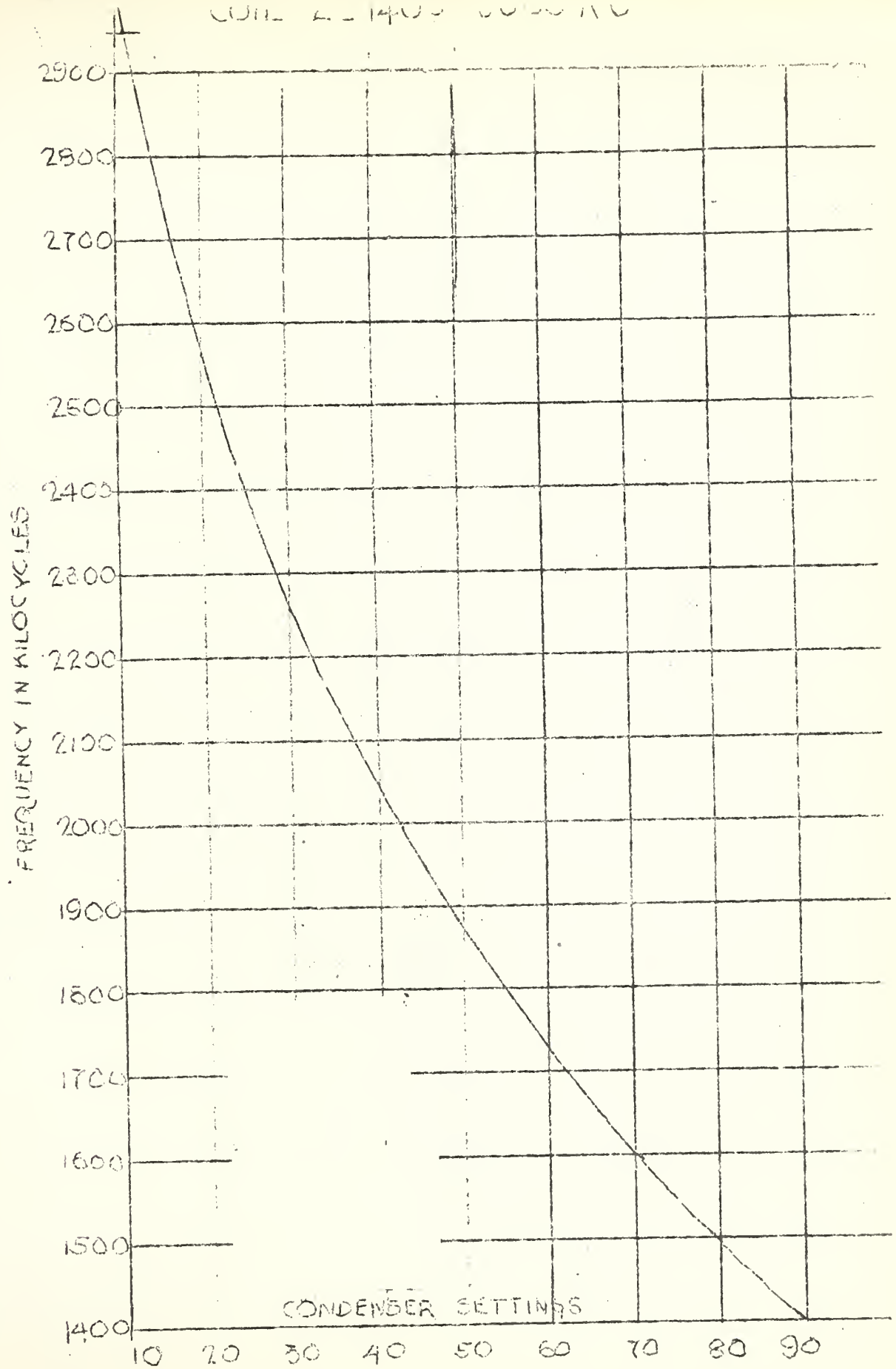ADJUST B TO 2700 KC --   "   "   "   "

COIL 1_ 550-1500 KC

FIG. 7 a.

FIG. 7 b